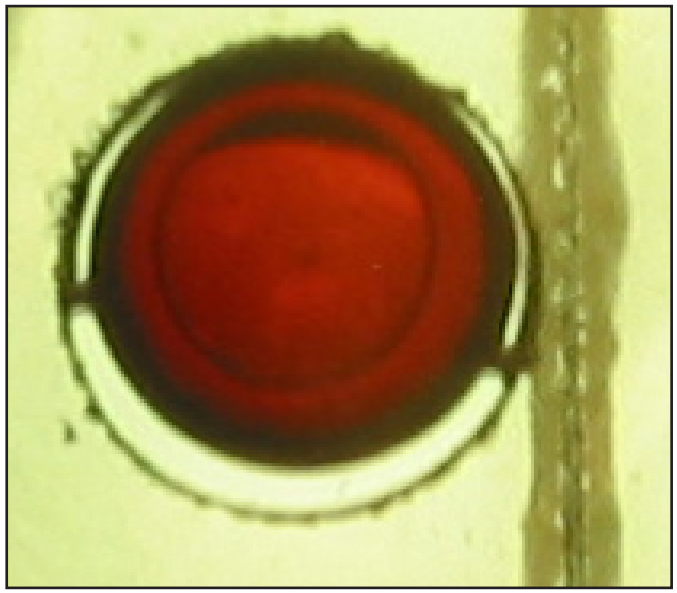
Dielectrophoresis of Liquid Deuterium for IFE Target Filling



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20th Target Fabrication Meeting
Santa Fe, NM
20–24 May 2012

Summary

Foam shells have been filled using dielectrophoresis

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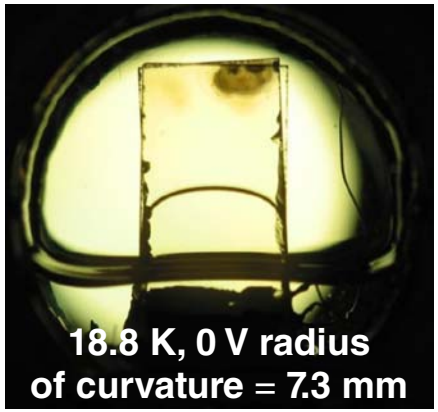
- There is a need to fill IFE targets more quickly than by permeation
- Basic predictions of dielectrophoresis are confirmed for liquid D_2 using parallel vertical electrodes
- Two methods of dispensing a small volume of liquid D_2 from a larger reservoir are demonstrated
- A volume of liquid has been wicked into a foam shell

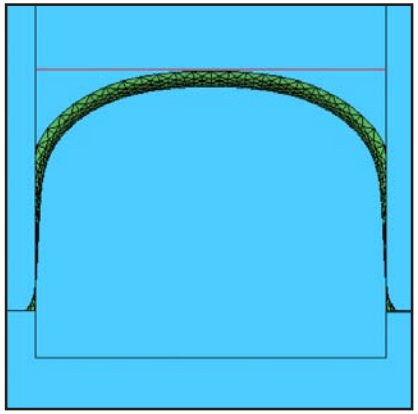
This is a first demonstration of dielectrophoretic behavior in a cryogenic liquid.

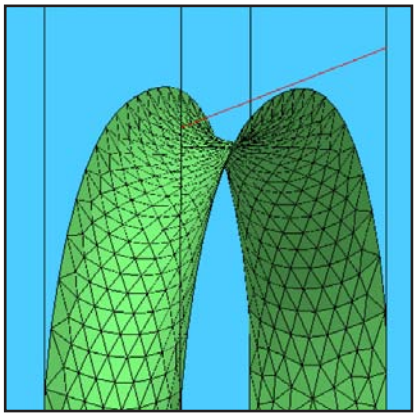
Acknowledgement

- Kyle Kentsch
- Eric Pan
- Weiqiang Wang
- Mark Wittman

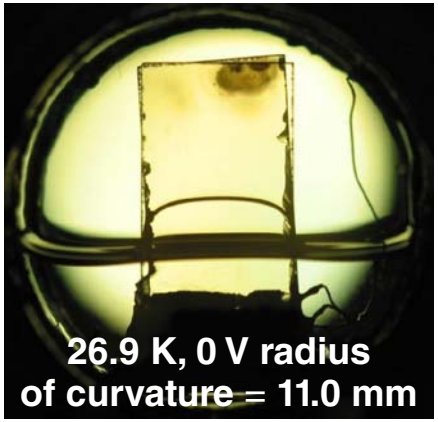
*Surface Evolver** software accurately predicts the shape of the liquid surface between electrodes by minimizing surface energy

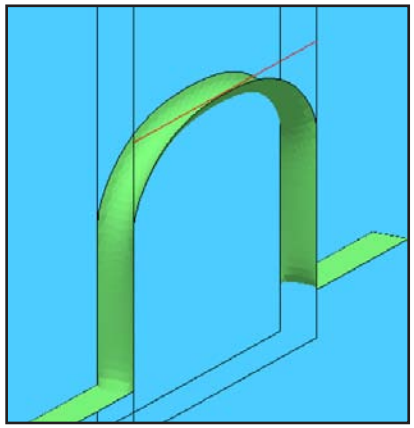






Matches height and curvature of upper left image





*K. Brakke, The Surface Evolver, ver. 2.30, Susquehanna University, Selinsgrove, PA, software available from http://www.susqu.edu/brakke/evolver.html, 1 January 2008.

A prediction of dielectrophoresis is verified: the height of a liquid column between parallel vertical electrodes

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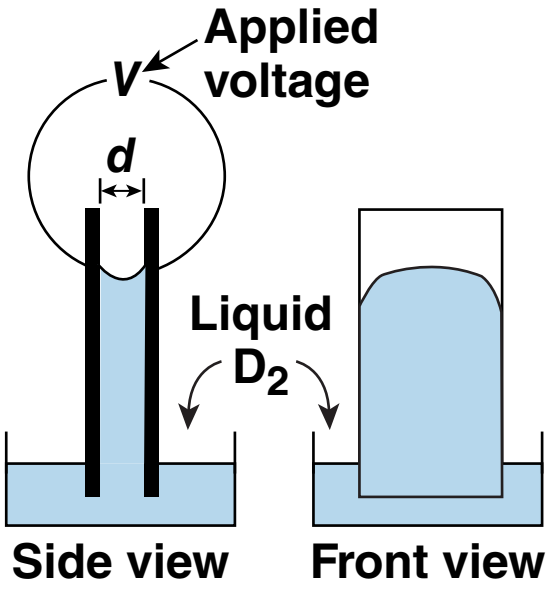
- A dielectric liquid in an electric field E is governed by

$$\nabla p_\ell = -\frac{1}{2} E^2 \nabla \epsilon - \rho_\ell g \hat{z}$$

where p_ℓ is hydrostatic pressure in the liquid, ϵ is permittivity, ρ_ℓ is the density of liquid, and $\hat{z}$ is the vertical unit vector



$$h_d = \frac{(\epsilon - \epsilon_0) V^2}{2 \rho_\ell g d^2}$$

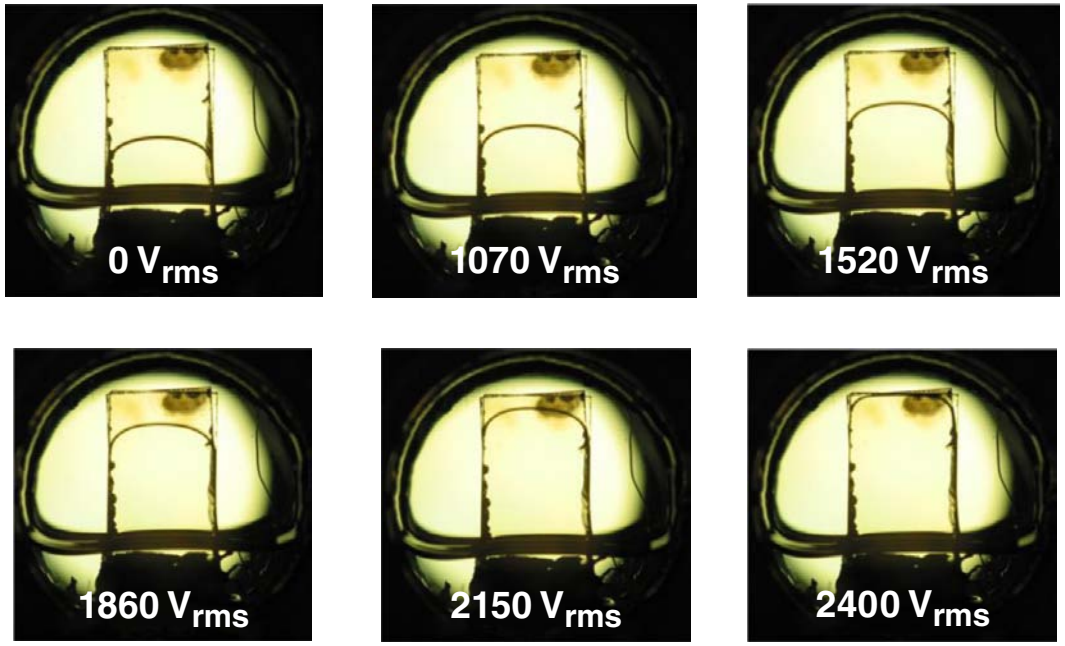
$$h_c = \frac{2 \gamma \cos(\theta)}{\rho_\ell g d}$$

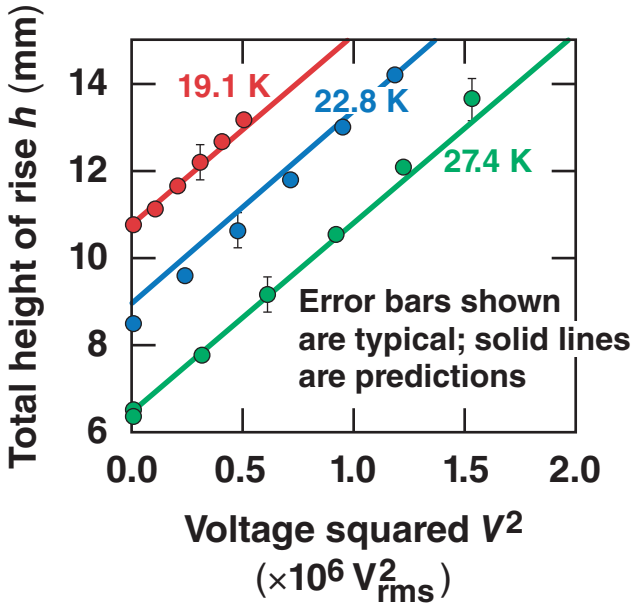
γ = surface tension

θ = contact angle

- For the hydrogens, $\theta = 0$ for contact with nearly all materials

The height of rise of a column of liquid D_2 between parallel plates is accurately predicted





Electrodes: glass coated with indium tin oxide
Width = 7.6 mm
Gap = 0.86 mm

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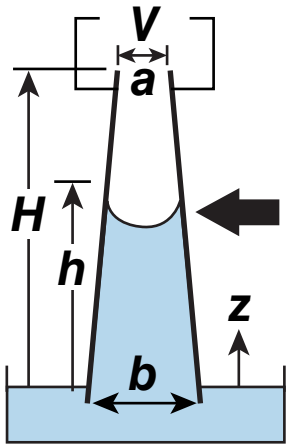
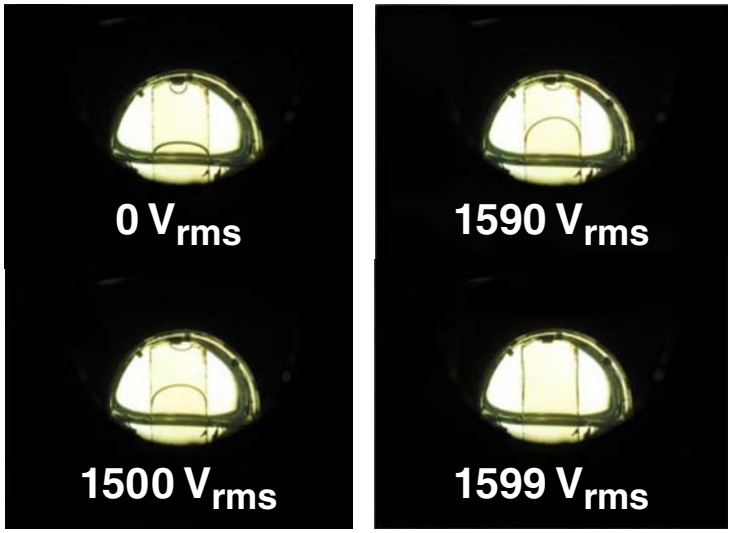
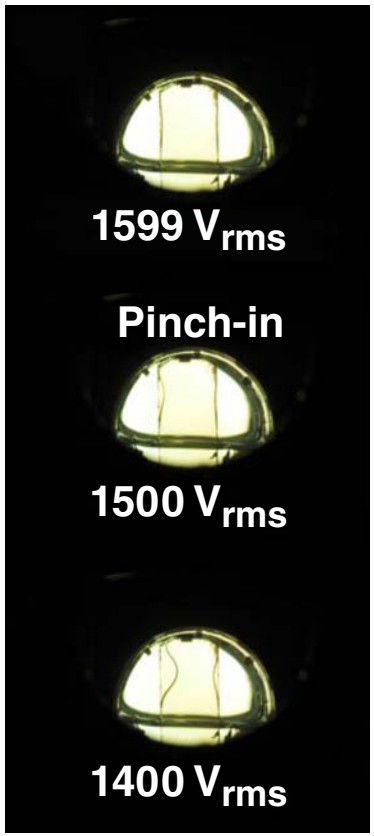
Converging electrodes are used to dispense a volume of liquid from the larger bath by "bifurcation"

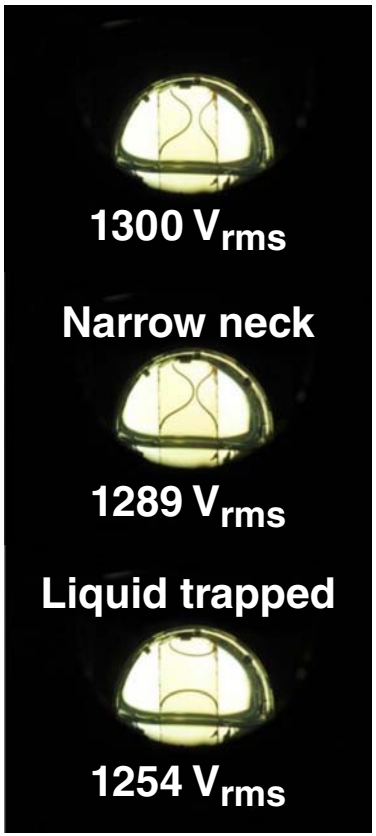


Experimental view direction through transparent electrodes



Liquid height as a function of voltage has a double-valued solution





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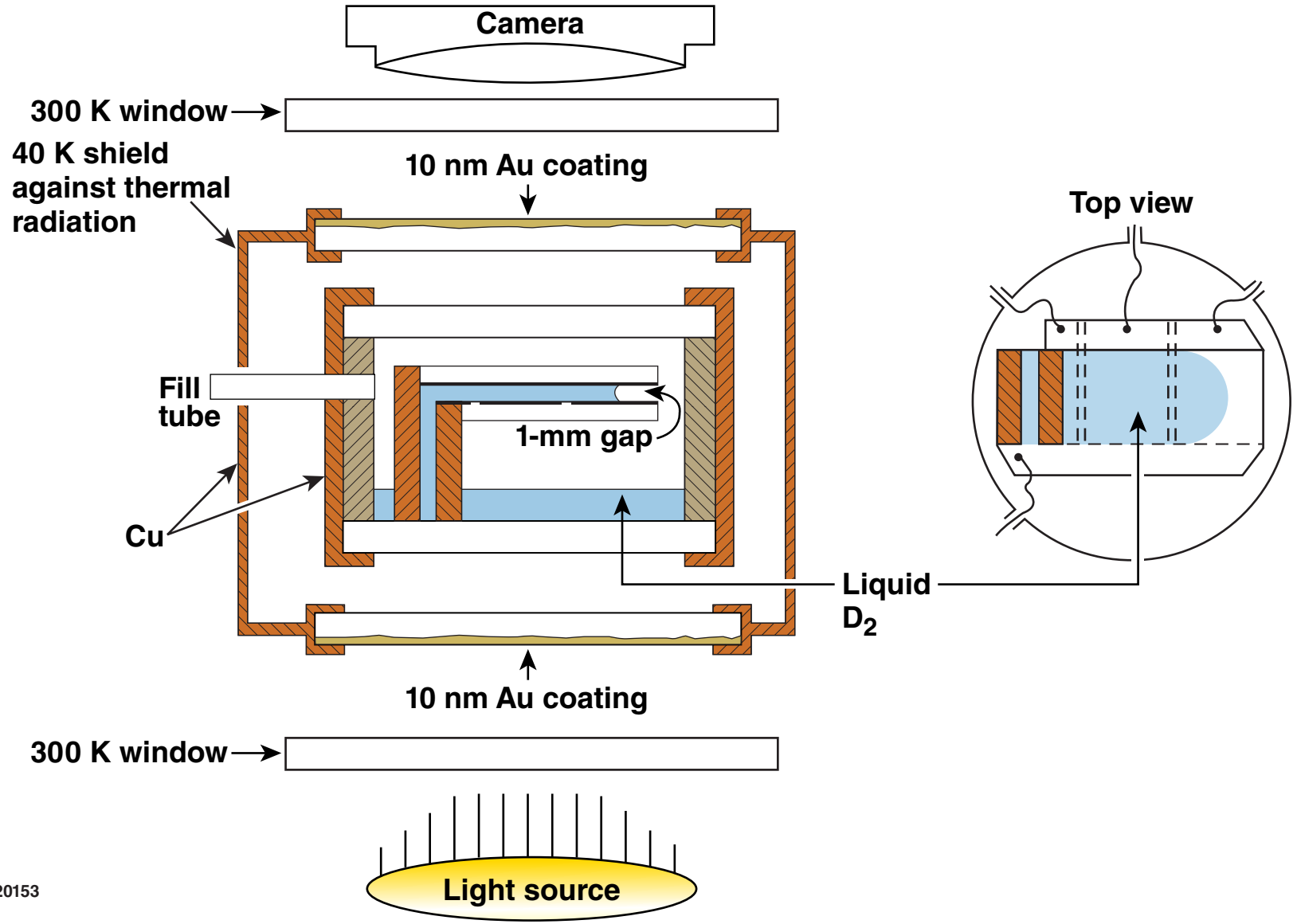
Vertical electrodes lift the liquid D_2 column to horizontal electrodes, allowing for a volume of liquid to be dispensed



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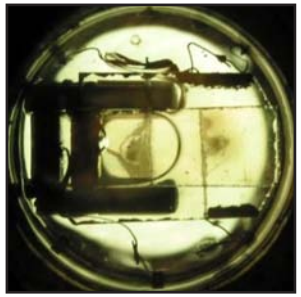
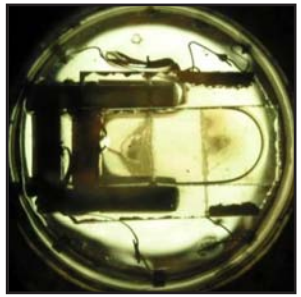
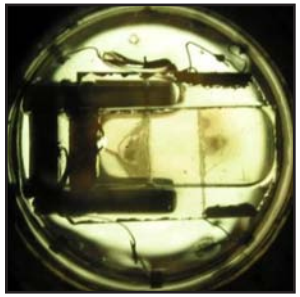
Liquid D_2 is lifted and moved horizontally, then a separate volume is dispensed by de-powering the lifting electrodes



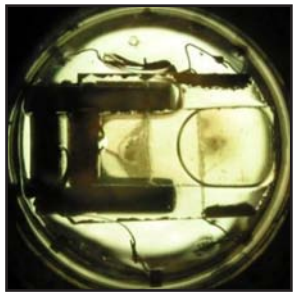
1.4 KV to all four electrodes



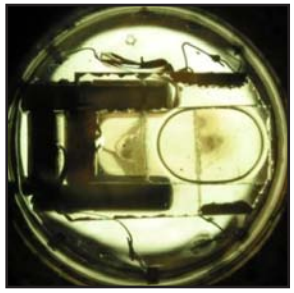
1.6 KV to all four electrodes



1.7 KV to all four electrodes



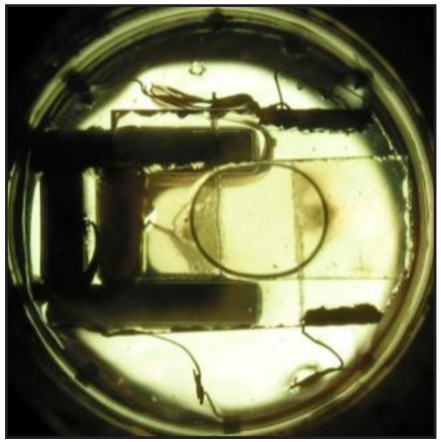
1.9 KV to two electrodes on right



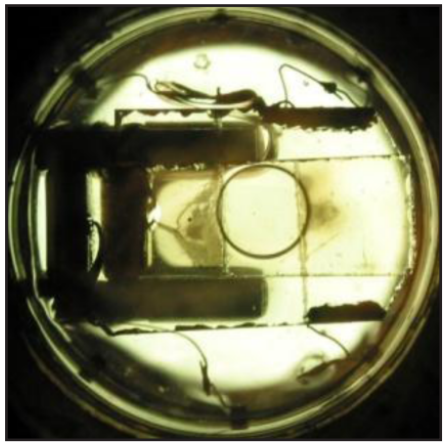
0.3 KV to two electrodes on right

Volume is approximately 28 μL as required by an IFE target.

The volume of liquid D_2 that is dispensed depends on the initial voltage

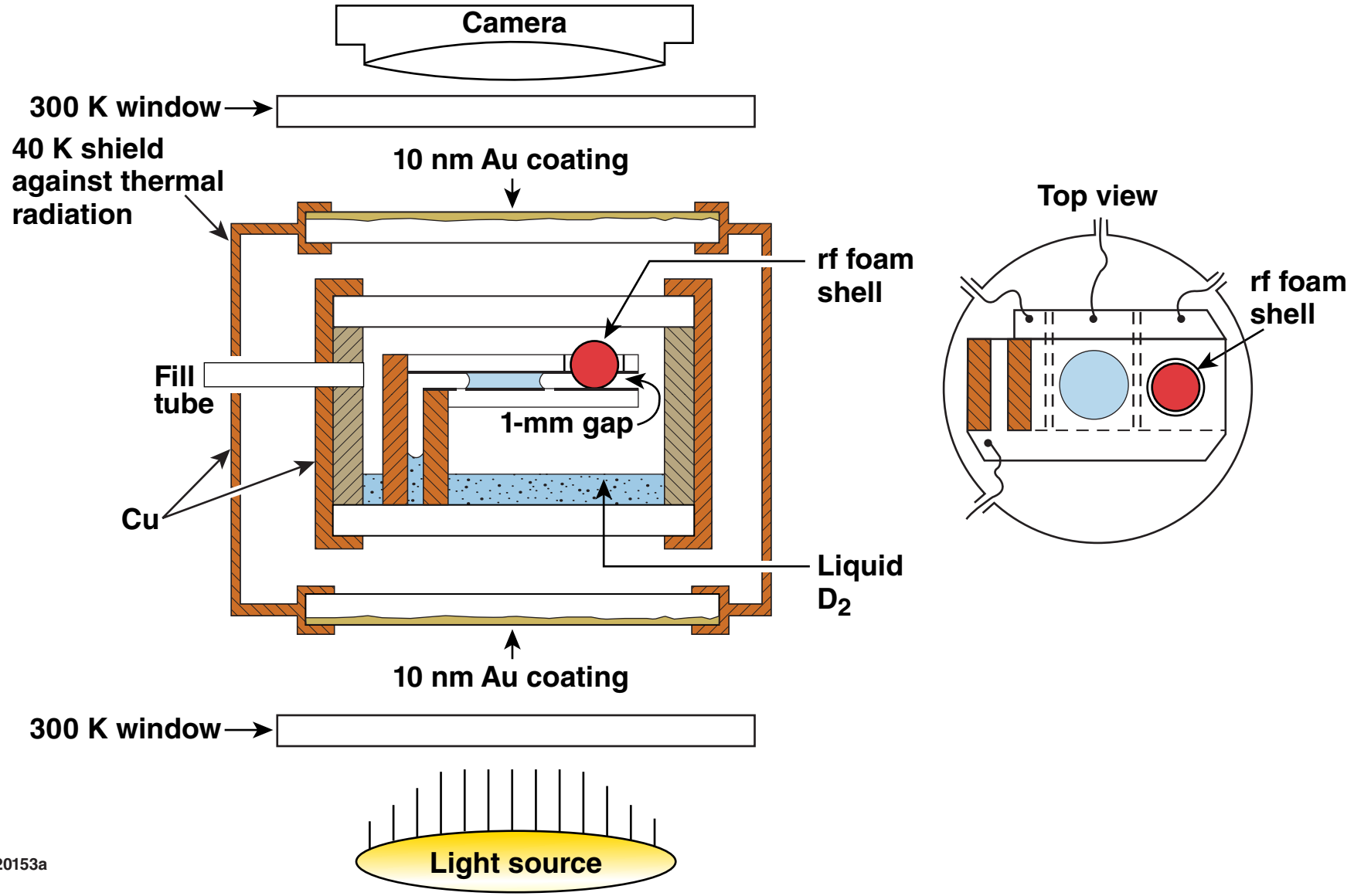


~23 μL
Initial voltage $\simeq$ 1.6 kV



~12 μL
Initial voltage $\simeq$ 1.5 kV

A foam shell is placed into the region between the electrodes



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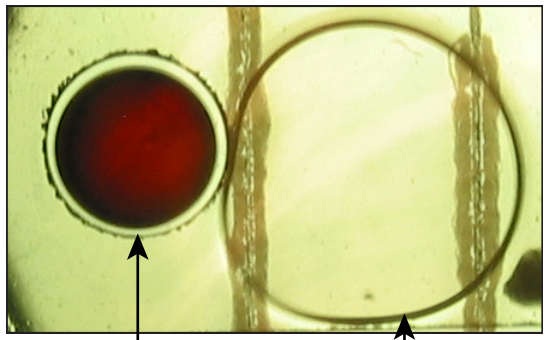
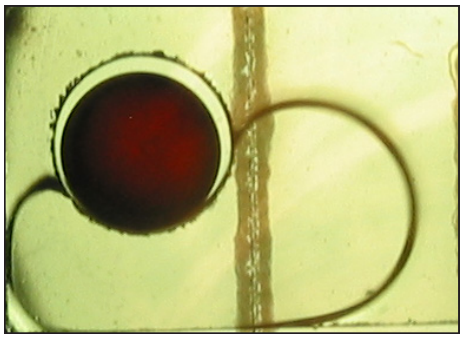
Liquid D_2 (14 μL) is rapidly absorbed (<10 s) into a foam shell at 25 K

ITO-coated electrodes

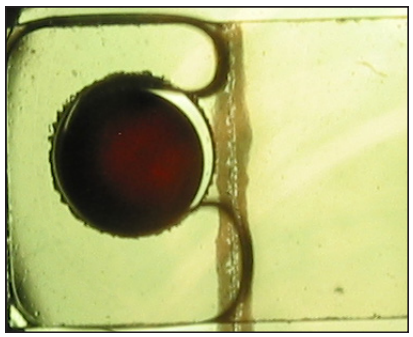


(i) 3.2-mm-diam 0.1-gm/cc rf foam shell (160-μm wall)

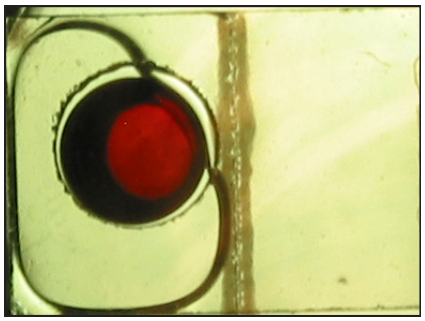
Liquid D_2 droplet



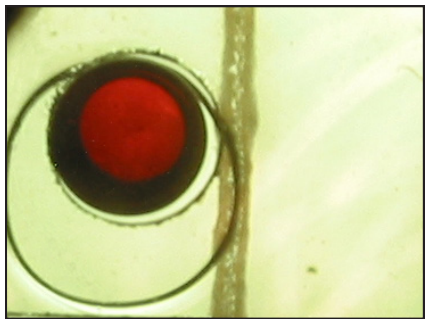
(ii) Liquid moving to the electrode containing foam shell



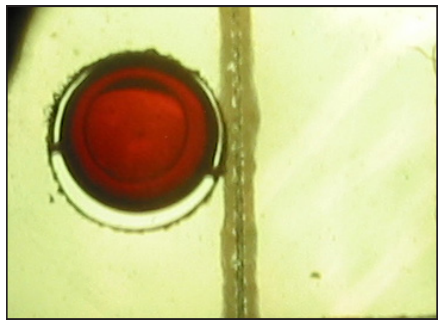
(iii) Liquid encapsulating and infiltrating the foam shell



(iv) Encapsulation and infiltration continues...



(v) Liquid infiltrating the foam wall



(vi) Liquid fully absorbed in the foam wall, shell void is not filled

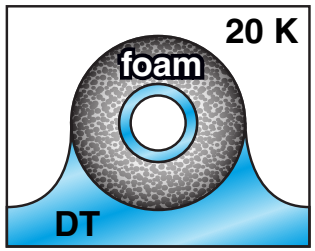
E19655a

Further work is needed

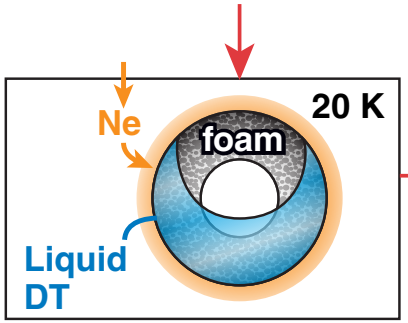
- A filled foam shell needs to be coated while cold with a barrier against leakage
- Greater precision is needed in generating the desired volume
- The desired amount of liquid needs to be obtained inside the cavity of the shell
- Dielectrophoresis needs to be tried with DT

The ability to dispense and move droplets of liquid cryogen provides another way for loading DT into shells

1. Form liquid DT into discrete droplets
2. Wick liquid into the foam shell



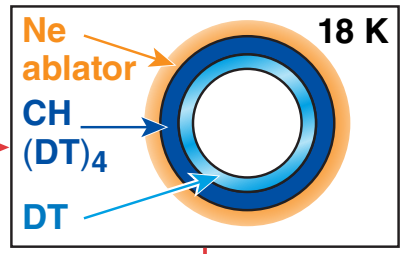
3. Condense Ne (Ar,Kr,Xe) as a barrier coating onto the foam



Transport electrostatically

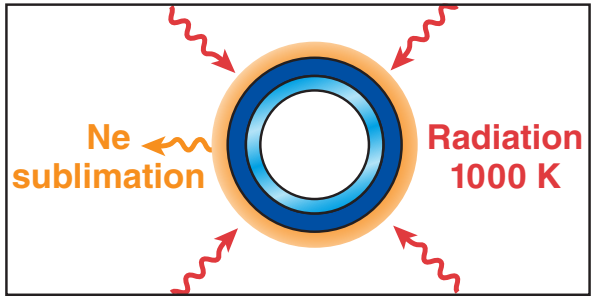
Thermal gradient
20 K → 18 K

4. Form ice layer – move through a thermal gradient (20 K → 19.5 K) at 0.001 K/5 min



5. Inject target – Ne overcoat ablated during transit

Tailor Ne thickness to insulate the target



An electromechanical microfluidic scheme is proposed for the cryogenic aspects of forming targets.

T2360h

Summary/Conclusions

Foam shells have been filled using dielectrophoresis

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